NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3388

A FIBROUS-GLASS COMPACT AS A PERMEABLE MATERIAL FOR BOUNDARY-LAYER-CONTROL APPLICATIONS USING AREA SUCTION

By Robert E. Dannenberg, James A. Weiberg, and
Bruno J. Gambucci

Ames Aeronautical Laboratory
Moffett Field, Calif.

Washington
January 1955

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3388

A FIBROUS-GLASS COMPACT AS A PERMEABLE MATERIAL FOR BOUNDARY-LAYER-CONTROL APPLICATIONS USING AREA SUCTION

By Robert E. Dannenberg, James A. Weiberg, and
Bruno J. Gambucci

SUMMARY

Measurements were made of the resistance of fibrous-glass compacts to normal air flow. The flow resistance was related to the thickness and density. As a porous material for boundary-layer-control applications using area suction, the fibrous-glass compact could be made to any desired thickness and permeability and sandwiched between perforated rigid surfaces.

INTRODUCTION

In the course of an investigation of the use of area suction for boundary-layer control, a survey was made of the flow-resistance characteristics of a number of commercially available permeable materials (ref. 1). Among these, filter paper, felt cloths, and sintered metals were used in wind-tunnel or flight-test applications.

In the present report, the flow resistance of fibrous-glass compacts (bonded with phenolic resin) of several densities and thicknesses are presented for a range of differential pressures across the compacts. The densities of the compacts were varied independently of thickness to produce various stepped and tapered permeabilities.

The authors wish to express their appreciation to the Owens-Corning Fiberglas Corporation, Pacific Coast Division, Santa Clara, California, particularly Mr. Irving N. Smith, for supplying technical advice and the material (Fiberglas B-fiber, phenolic bonded) used in the fabrication of the fibrous-glass compacts.

NOTATION

A	frontal area of porous sample, sq ft
g	acceleration due to gravity, ft/sec^2
H	total pressure, lb/sq ft
Δh	pressure difference across porous material, in. water
p	static pressure, lb/sq ft
Q	volume rate of flow, cu ft/sec
t	temperature, $^{\circ}$F
v	suction air velocity, normal to the upstream surface of the porous material, $\frac{w}{\rho g A}$, ft/sec
w	weight rate of air flow, lb/sec
τ	index of resistivity, defined as the pressure difference in inches of water required to induce a suction air velocity normal to the surface of 1 foot per second through a porous material of a given thickness
φ	value of the exponent used in the equation $\Delta h = \tau v^{\varphi}$
ρ	mass density of air just upstream of porous sample, slugs/cu ft

Subscript

1	station upstream of porous material

APPARATUS AND TEST METHODS

The resistance of the fibrous-glass compacts to air flow normal to the surface was measured by means of the apparatus shown in figure 1. The suction pressure required to induce flow through the compact was provided by a vacuum pump. The air was drawn through the compact and through a standard A.S.M.E. orifice meter (ref. 2) and the flow was controlled by a gate valve downstream of the orifice meter. The orifice size and operating procedure were kept within the limitations prescribed in reference 2 so as to keep the accuracy of flow measurement within ±1 percent. Thermocouples were installed in the duct to measure the air temperature near the compact and near the orifice meter. The apparatus was checked at the start and completion of each test run to make certain there were no leaks in the duct.

Compacts of uniform permeability were tested in the circular duct section shown in figure 1(b), whereas compacts of variable permeability were tested in the square section, figure 1(a). The sections had equal cross-sectional areas of 19.63 square inches. The compacts to be tested were held firmly between flanges sealed with a nonporous tape. The upstream side of the compact was open to the atmosphere.

As the compacts tested were not strong enough to support themselves, they were backed with a wire cloth (16-mesh, 0.023 inch diameter wire, ref. 3). The pressure loss across the wire cloth was negligible throughout the range of air velocities tested.

The accumulation of dust from the suction air during the testing (approximately 25 minutes per sample) discolored the exposed surface of the compact as can be noted in figure 2. The test apparatus was located in a shop-type concrete room and normal dust-laden air was drawn through the compacts. A test was conducted to determine the effect of the dust on the permeability and to ascertain if a filter would be required upstream of the test specimen to clean the air prior to its passage through the compact. A 3/16-inch-thick compact having a density of 10 pounds per cubic foot was tested continuously until a total of 60 hours had accumulated. The pressure difference across the compact was held constant at a value corresponding to a suction air velocity of 5 feet per second at the start of the test. The flow velocity showed no appreciable change during the first 10 hours of operation, but gradually decreased thereafter with increasing time. At the end of 60 hours the flow velocity was reduced 30 percent. The compact was removed from the duct and was found to have collected a layer of dust approximately 1/32-inch thick on the upstream face. The compact was then cleaned with a high-pressure reverse flow. After cleaning, the flow velocity increased to within 5 percent of its initial value. Because of the short duration of the testing time for each sample, a cleaning filter was not installed in the system.

MATERIAL

The fibrous-glass compacts tested were fabricated from blown-glass fibers with 25 percent by weight of phenolic resin as a binder as specified in reference 4. In the manufacturing process, the glass fibers are attenuated to the desired degree of fineness (0.00015-inch mean diameter) by a blast of hot gases and are then collected on a moving screen in the form of a continuous mat or blanket. Just prior to collection on the screen, while the fibers are suspended in the moving gas stream, liquid phenolic resin is applied as a spray. In the uncured state, the material has somewhat the appearance of oily cotton (fig. 2). In forming a compact, the uncured material is placed in a die of the desired shape and heated to 300° to 350° F for times ranging upward from 3 minutes, depending on the thickness and density of the compact. Under heat the liquid resin converts to a hard infusible solid which permanently binds the fiber structure in the shape and thickness imposed by the die. The only pressure required is that sufficient to close the die. In the cured or finished state, the compact has a reddish-brown color. The density of a compact is controlled by the weight per unit area of the uncured material and the thickness of the cured or finished compact.

RESULTS AND DISCUSSION

Uniform Permeability

The densities and thicknesses of the fibrous-glass compacts tested are indicated in figure 3 and are listed in table I. The flow-resistance characteristics of the compacts are shown in figure 4 for the air flow normal to the surface. The upstream face of the compact was open to the atmosphere (average $H_1 = 2116$ lb/sq ft and $t_1 = 71^\circ$ F). Examination of the figure indicates that for small pressure differences across the compact, the pressure difference increased as a constant power of the velocity. With larger pressure differences, the pressure difference increased at a more rapid rate. Within the linear range of the logarithmic plots of figure 4, the flow resistance of the compacts can be expressed in an exponential form relating the suction velocity v to the pressure difference Δh as

$$\Delta h = \tau v^{\varphi}$$

where the index of resistivity τ is defined as the pressure difference in inches of water required to induce a suction air velocity normal to the surface of 1 foot per second through a porous material of a given thickness. The values of τ and φ are tabulated in table I for the compacts tested. The value of the velocity above which the value of φ increases is also given in the table.

The range of τ obtainable with fibrous-glass compacts is as large as that noted for granular or fibrous types of porous media in reference 1. The air-flow characteristics, as shown in figure 4, are similar to those for other types of fibrous porous materials, for example, felt cloth. For a given value of τ, curves for the fibrous-glass compact and felt cloth were, for practical purposes, the same.

In order to ascertain the repeatability of the value τ, swatches were taken from a batch of uncured material and a number of 3/16-inch specimens of two different densities (6 and 20 lb/cu ft) were fabricated and tested. The results indicated that the value of τ differed by less than ±4 percent of the value noted from figure 4. The value of φ was found to remain constant.

The thickness and density of the fibrous-glass compacts were found to be related to the index of resistivity τ as indicated in figure 5. These data are applicable only to compacts fabricated from a given batch of blown-glass fibers (type II of ref. 4).

Compacts fabricated from a different batch with the same manufacturer's designation differed by as much as 20 percent in the value of τ for the same density and thickness as compared to the data in figures 4 and 5. However, the value of τ for compacts made from swatches taken from this different batch agreed within ±4 percent.

All data presented in this report were obtained from compacts fabricated from swatches taken from the same batch of uncured material.

Variable Permeability

In general, it is usually advantageous in an application of area suction, from the standpoint of the suction power required, to vary in the chordwise and spanwise directions the suction-air-velocity distributions (ref. 5). Velocity variation is achieved by adding more material in the regions that are to have less permeability. The stepped or tapered arrangements of permeability investigated are shown in figures 6, 7, and 8. The finished thickness of each of these compacts was the same (3/16 in.).

The permeability distributions for the arrangements shown in figures 6(a) and 7(a) were arbitrarily selected. The values of τ for the densities used in each increment were calculated with the aid of figure 5. Calculated suction-velocity distributions shown in figures 6(b) and 7(b) were obtained by interpolation from figure 4(b) for values of τ equal to those used. Taking into account the ratio of the area of a given permeability to the total area, the computed and measured volume rates of flow were compared (for equal values of Δh) as shown in figures 6(c) and 7(c).

A similar comparison is shown in figure 8(c) for the tapered arrangement. In this case, the compact was fabricated by holding the uncured material in a jig contoured for the desired taper. A band saw, with the set removed from the teeth, was used to cut the material. The dark threads in the photograph of the finished compact in figure 8(a) are for identification purposes. Examination of figures 6(c), 7(c), and 8(c) reveals that the agreement between the calculated and measured flow quantities was within the limits noted previously for values of τ of sample compacts with uniform permeability.

Installation of Compact for an Area Suction Application

The fibrous-glass compact is ideally suited for area suction applications for lift control on thin airfoils where space is at a premium and large variations in the permeability are required in a relatively small area. The fibrous-glass compact also has the advantages of being lightweight, chemically inert, and comparatively inexpensive to manufacture. A practical installation would require rigid supporting surfaces such as perforated sheets. The fibrous-glass compact can be formed to any shape desired by the use of a suitable die in the curing and compacting process. An installation of a molded compact in a flap on a 6-percent thick airfoil is shown in figure 9.

The unique feature of the arrangement is that the permeability can be varied independently of the thickness - an important factor in laboratory tests. Constant thickness compacts can be interchanged independently of the surface sheet for evaluation of the effects of different suction velocity distributions on aerodynamic performance. A 1/8-inch thick compact can be equipped with a tenfold variation in τ, a variation sufficient to cover the range of permeabilities required for area suction applications. To obtain this variation with other types of porous materials (ref. 1) would require combinations of different sheets of sintered metals or various thicknesses of felt cloth.

In order to determine the effect of a perforated sheet on the flow-resistance characteristics of a fibrous-glass compact, various multihole sheets (table II) were installed to form the upstream surface for the compact with the tapered arrangement of permeability. The results are shown in figure 10. The added flow resistance of a perforated sheet, particularly for sheets with less than 15-percent open area, should be taken into account in the sandwich type of arrangement (fig. 9). However, in practical applications this probably would not be a problem since most common commercially available perforated materials have at least 15- to 20-percent open area.

CONCLUDING REMARKS

Measurements were made of the air-flow-resistance characteristics of fibrous-glass compacts consisting of blown-glass fibers and 25-percent phenolic resin by weight as the bonding agent. The permeability was controlled by the density and thickness of the compact. The permeability of constant thickness compacts was varied over the range generally required for applications of area suction for boundary-layer control.

In application, the compact could be molded to any desired shape and thickness and installed in a sandwich type of arrangement consisting of perforate metal sheets supporting a fibrous-glass compact interior.

The rigid supporting sheets could serve as structural members. Perforating only the portion of the surface sheet in the porous region would permit a joint-free installation. In operation the fibrous-glass compact could be removed and replaced if it became partially clogged.

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, Calif., Oct. 28, 1954

REFERENCES

1. Dannenberg, Robert E., Weiberg, James A., and Gambucci, Bruno J.: The Resistance to Air Flow of Porous Materials Suitable for Boundary-Layer-Control Applications Using Area Suction. NACA TN 3094, 1954.

2. Anon.: A.S.M.E. Power Test Codes – 1949. Supplement on Instruments and Apparatus. Part 5 – Measurement of Quantity of Materials. PTC 19.5; 4-1949, A.S.M.E., N. Y., 1949.

3. Anon.: Catalog No. 1249, Industrial Screens, The Colorado Fuel and Iron Corporation, Denver, Colo., 1949.

4. Anon.: Military Specification. Batting, Insulation, Glass Fibers. Type II. MIL-B-5924 (USAF) August 31, 1950.

5. Dannenberg, Robert E., and Weiberg, James A.: Effect of Type of Porous Surface and Suction Velocity Distribution on the Characteristics of a 10.5-Percent-Thick Airfoil With Area Suction. NACA TN 3093, 1953.

6. Anon.: Lektromesh Specification Sheet, The C.O. Jelliff Mfg. Corp., Southport, Conn., 1949.

7. Anon.: General Catalog No. 62, Perforated Materials, The Harrington and King Perforating Company, Chicago, Ill., 1950.

TABLE I.– CHARACTERISTICS OF FIBROUS-GLASS COMPACTS WITH UNIFORM PERMEABILITY

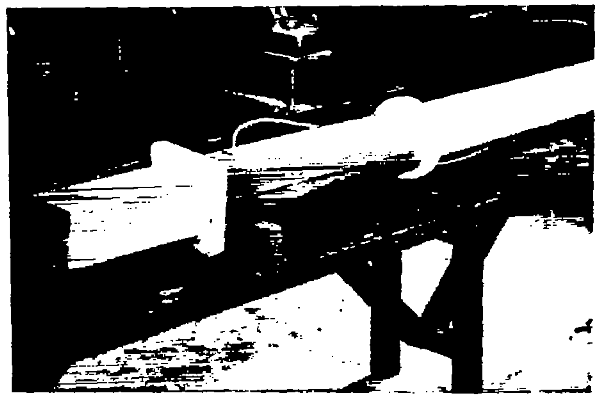
No.	Thickness, in.	Density, lb/cu ft	$\Delta h = \tau v^{\varphi}$ τ	φ	Limit v, for linearity, fps
1	1/8	3	0.21	1.24	18
2	↓	6	.59	1.16	13
3		10	1.4	1.08	7
4		20	4.6	1.03	5
5		30	10.3	1.05	5
6		40	21.3	1.05	4
7	3/16	6	1.0	1.04	8
8	↓	12	2.7	1.07	8
9		20	6.4	1.07	8
10		27	11.1	1.06	6
11		30	15.0	1.06	5
12	1/4	10	2.9	1.07	6
13	3/8	10	4.8	1.06	6
14	1/2	6	2.5	1.07	9
15	↓	10	6.0	1.05	7
16		20	17.0	1.06	5
17		30	43.0	1.05	2

NACA

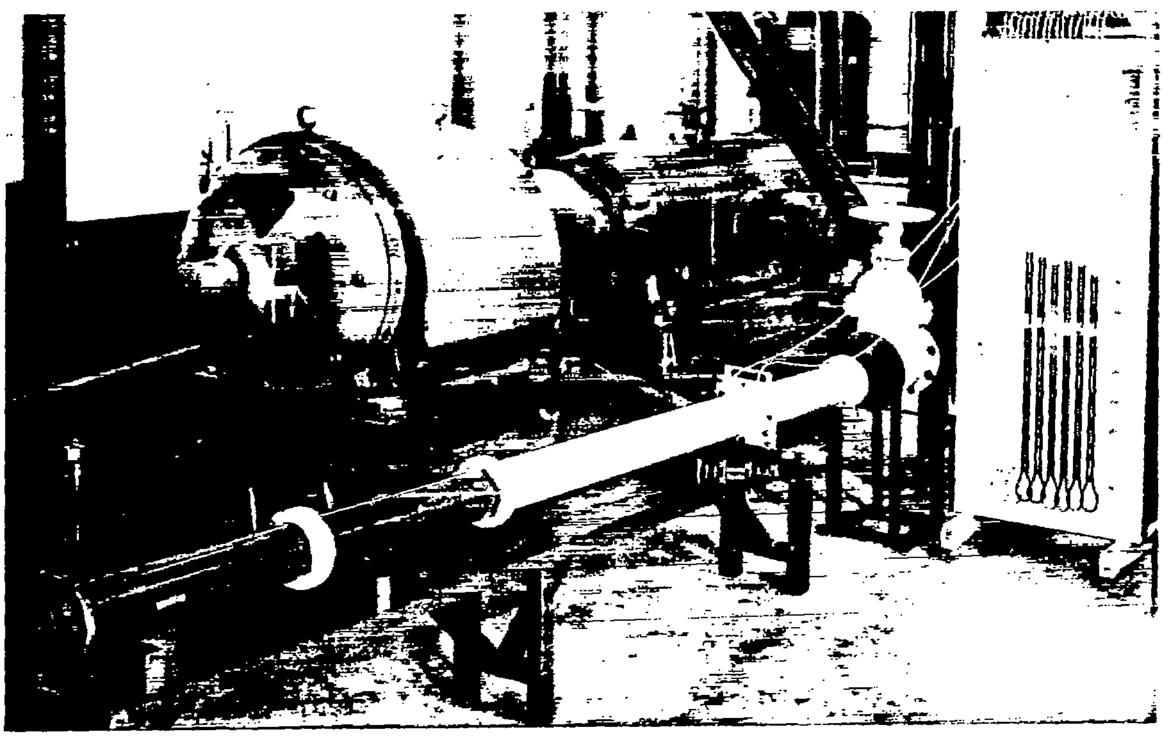
TABLE II.– CHARACTERISTICS OF MULTIHOLE SHEET MATERIALS PLACED ON UPSTREAM SIDE OF FIBROUS-GLASS COMPACT

No.	Manufacturer's designation	Ref-erence	Hole size, in.	Holes per sq in.	Percent open
18	65 count, square hole	6	0.005	4,225	10.5
19	No. 1/20 staggered	7	.050	57	11.2
20	0.022 inch staggered	7	.022	376	14.4
21	No. 0 staggered	7	.024	379	18
22	No. 00 staggered	7	.020	714	23
23	No. 22 slot, side staggered	7	.020×.115 slot, .050 centers	130	30
24	No. 4 straight	7	.050	169	33

NACA



(a) Square specimen holder (4.43–in. square).



(b) General arrangement of test setup with circular specimen holder (5.0–in. diameter).

Figure 1.– Duct for calibration of fibrous–glass compacts with normal air flow; specimen area = 19.63 square inches.

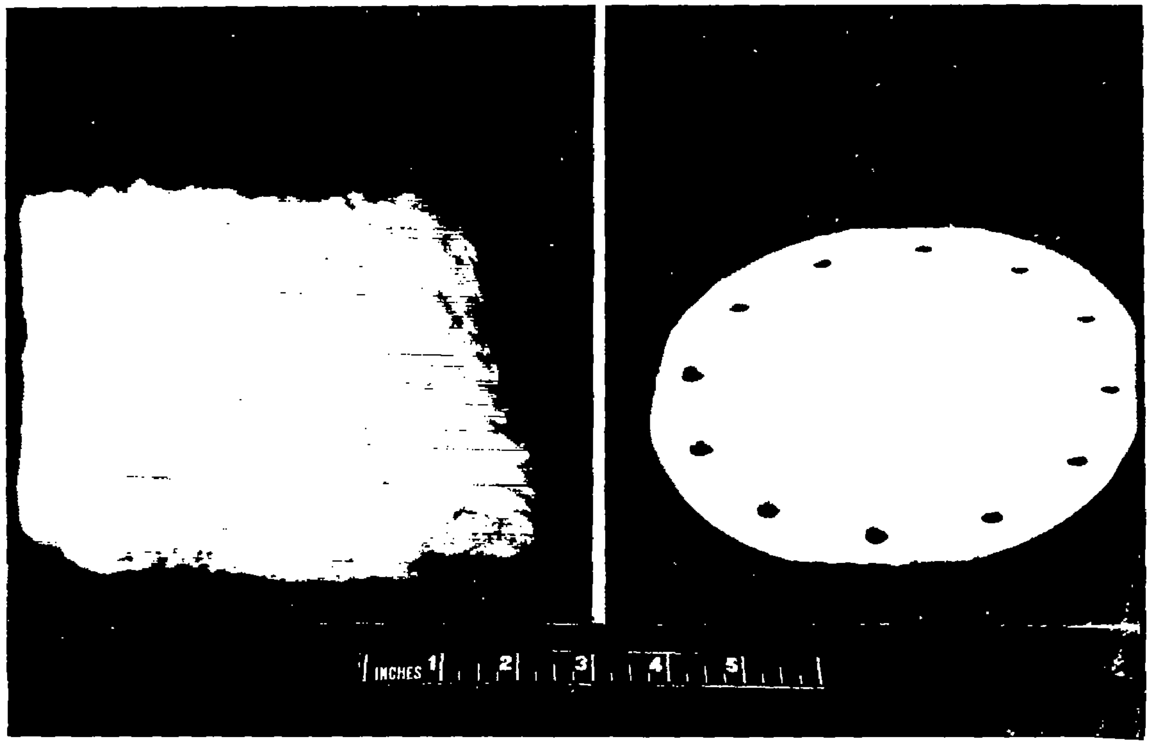


Figure 2.— Typical arrangement of fibrous-glass material before and after compacting and curing; uniform permeability; density = 6 pounds per cubic foot; thickness = 3/16 inch.

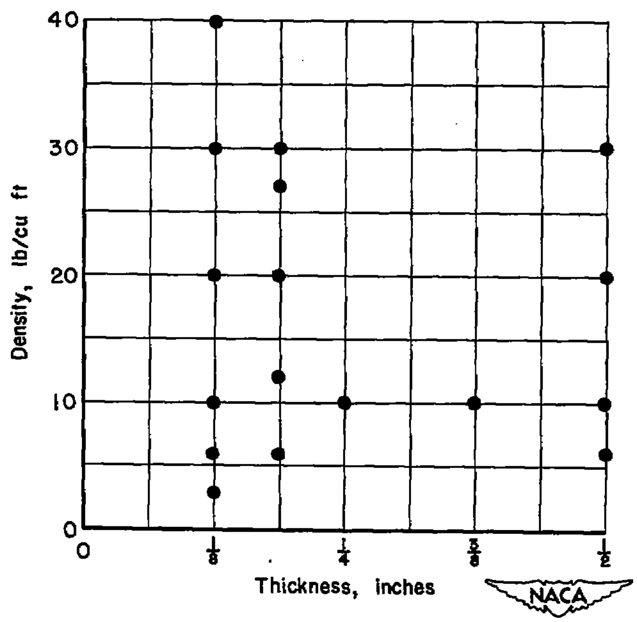
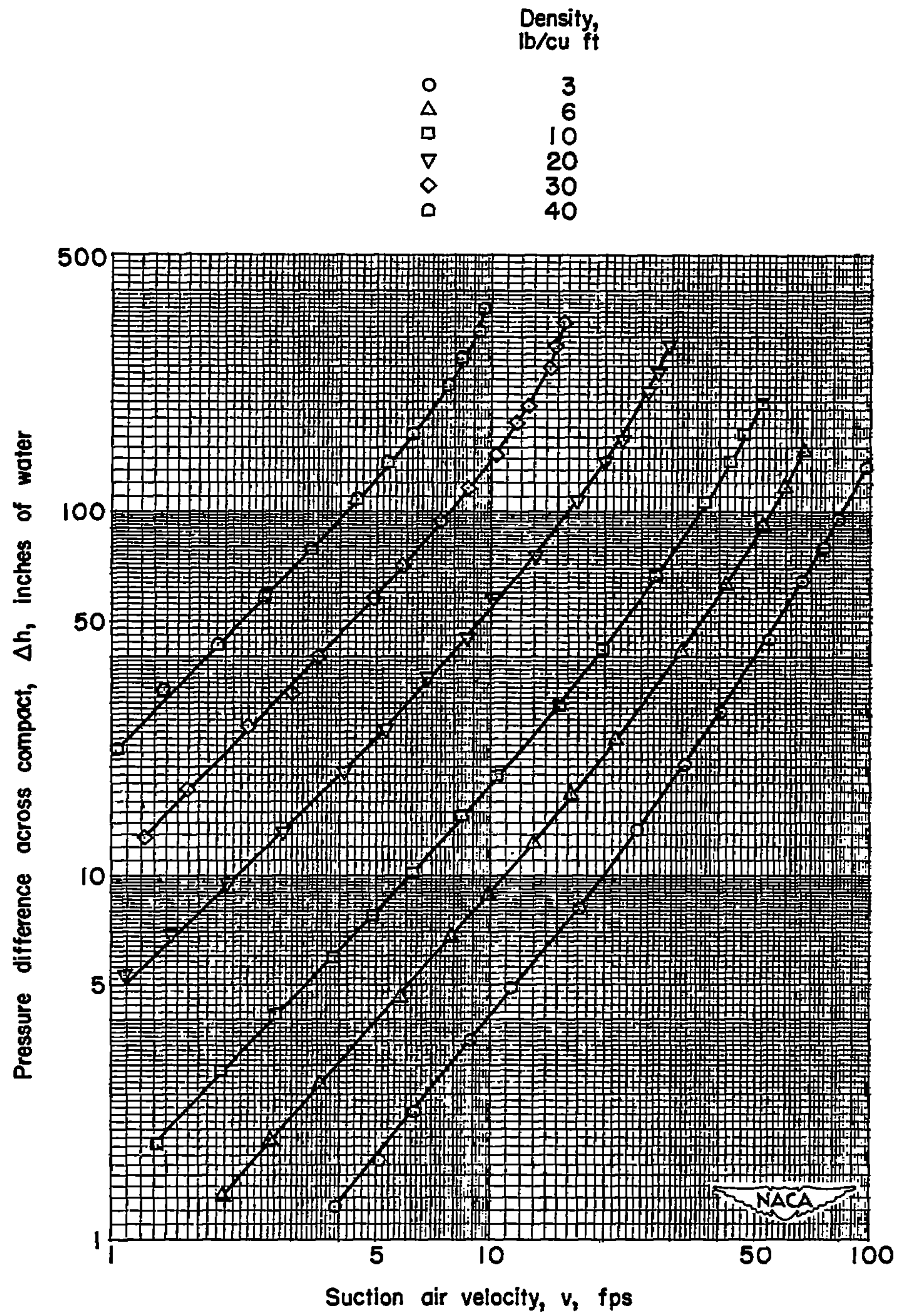
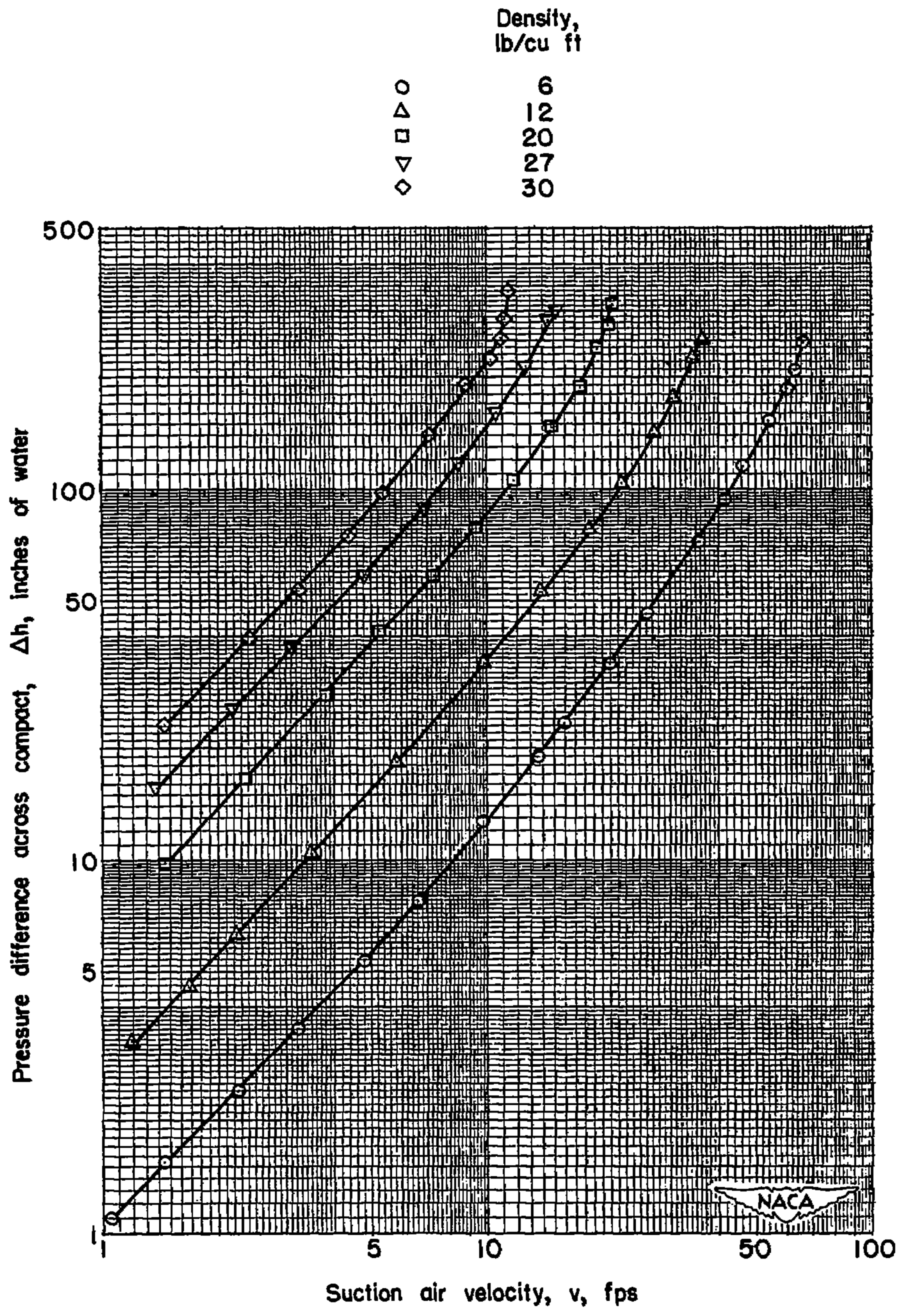


Figure 3.— Thickness and density of fibrous-glass compacts tested with uniform permeability.



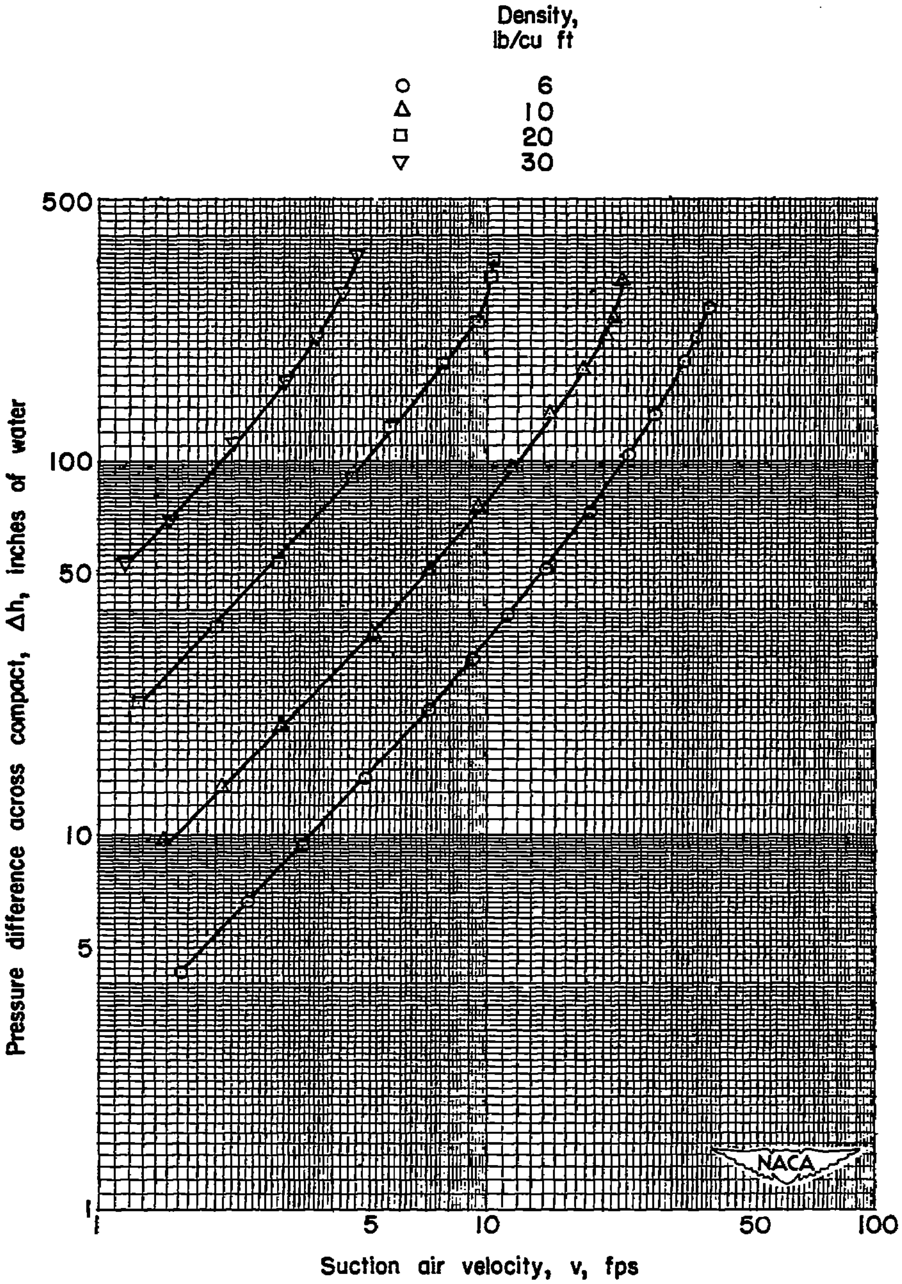
(a) $\frac{1}{8}$-inch thickness

Figure 4.- Resistance to air flow of various fibrous-glass compacts with uniform permeability for normal flow.



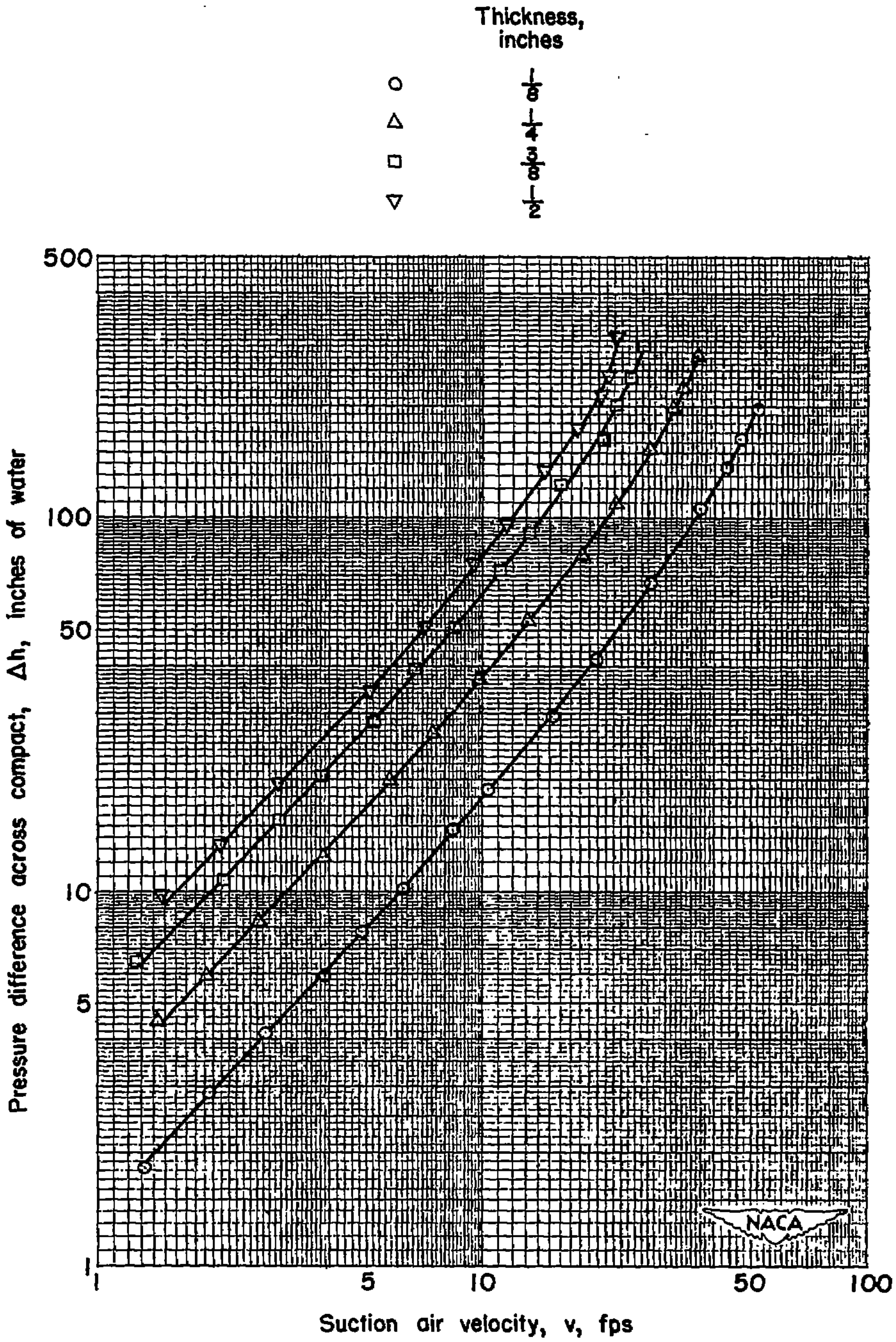
(b) $\frac{3}{16}$-inch thickness

Figure 4.– Continued.



(c) $\frac{1}{2}$-inch thickness

Figure 4.– Continued.



(d) Density of compact = 10 lb/cu ft

Figure 4.– Concluded.

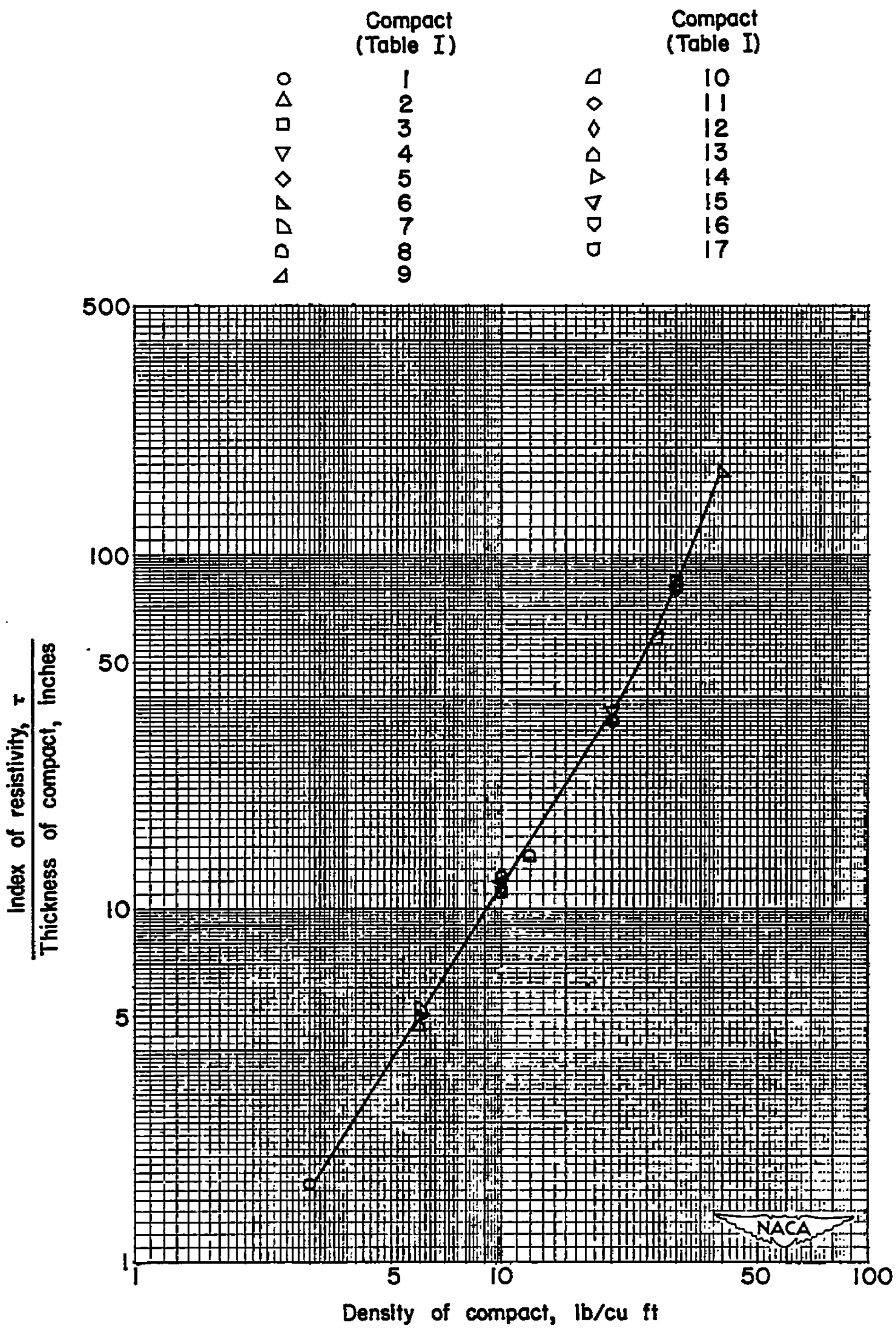
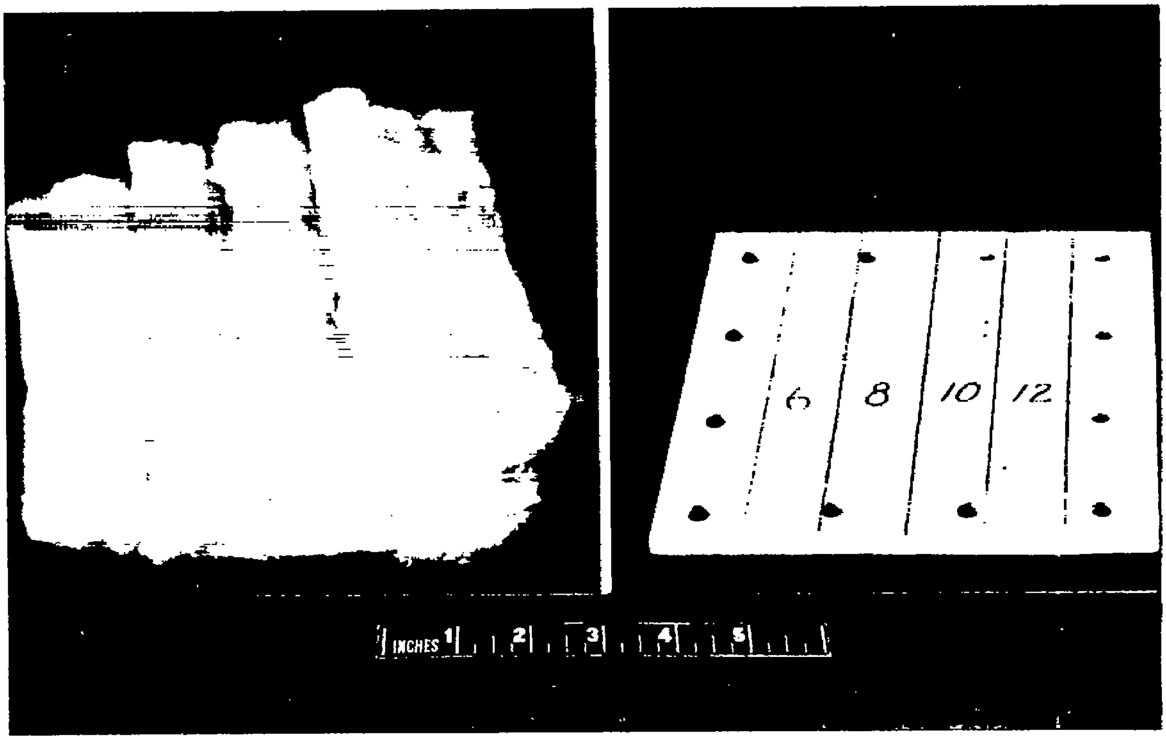
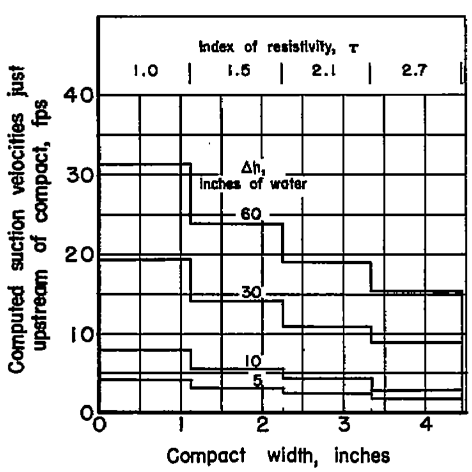


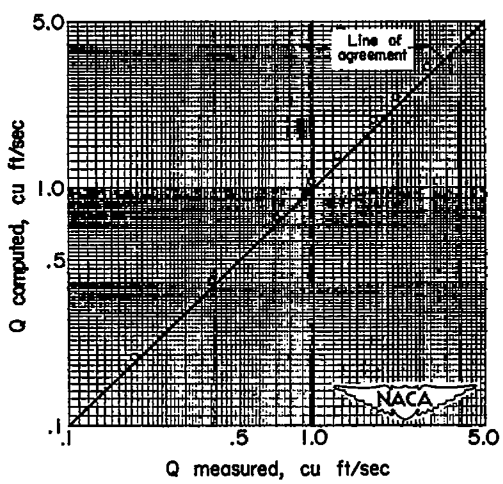
Figure 5.- Correlation of the physical properties of fibrous-glass compacts with the index of resistivity τ; normal flow.



(a) Material arrangement before and after compacting into stepped arrangement of permeability. Compacted density noted in photograph.

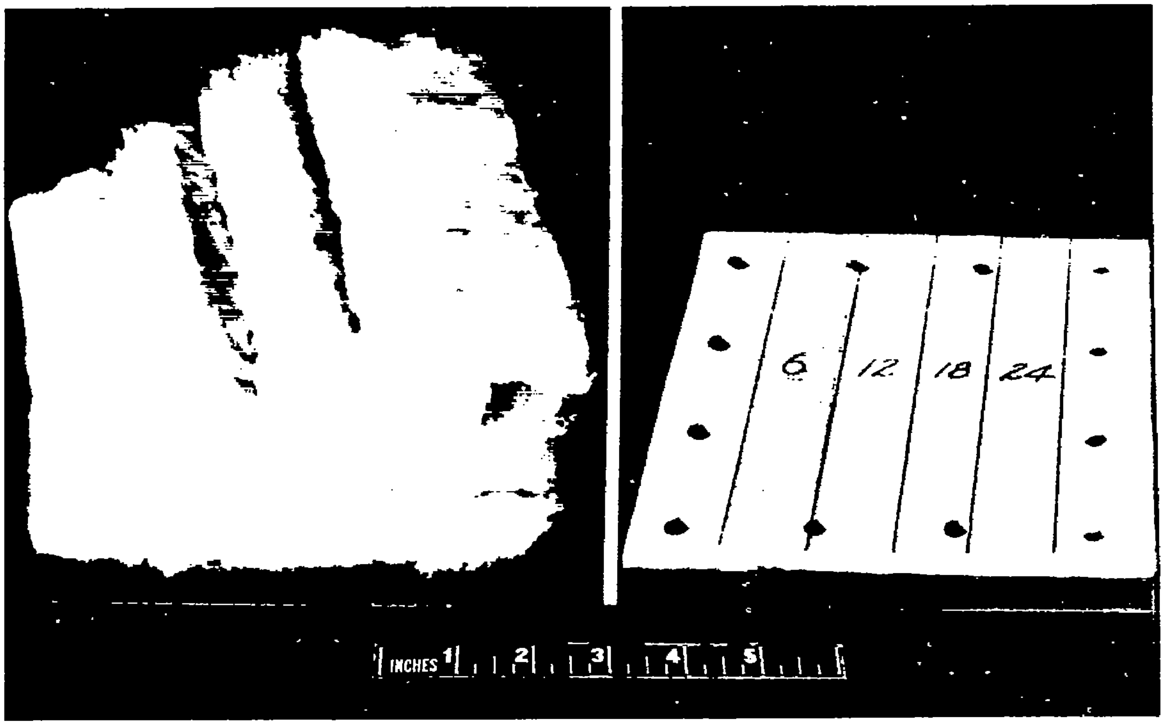


(b) Computed suction-velocity distribution.

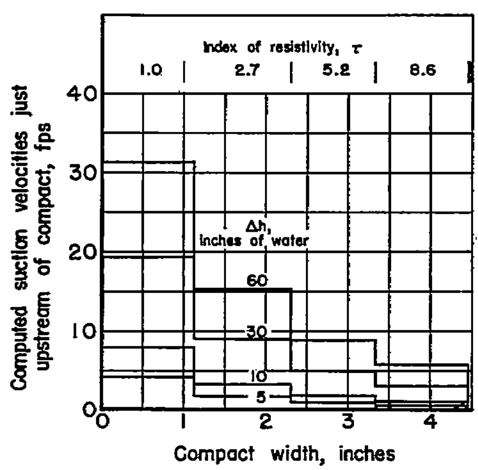


(c) Correlation of computed and measured flow rates for equal values of Δh.

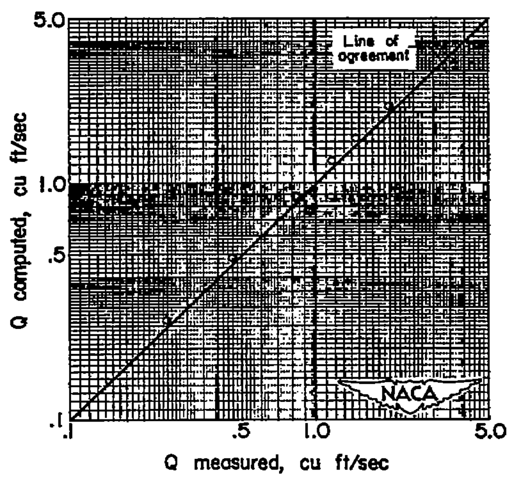
Figure 6.- Fibrous-glass compact with stepped permeability; density from 6 to 12 pounds per cubic foot; thickness = 3/16 inch.



(a) Material arrangement before and after compacting into stepped arrangement of permeability. Compacted density noted in photograph.

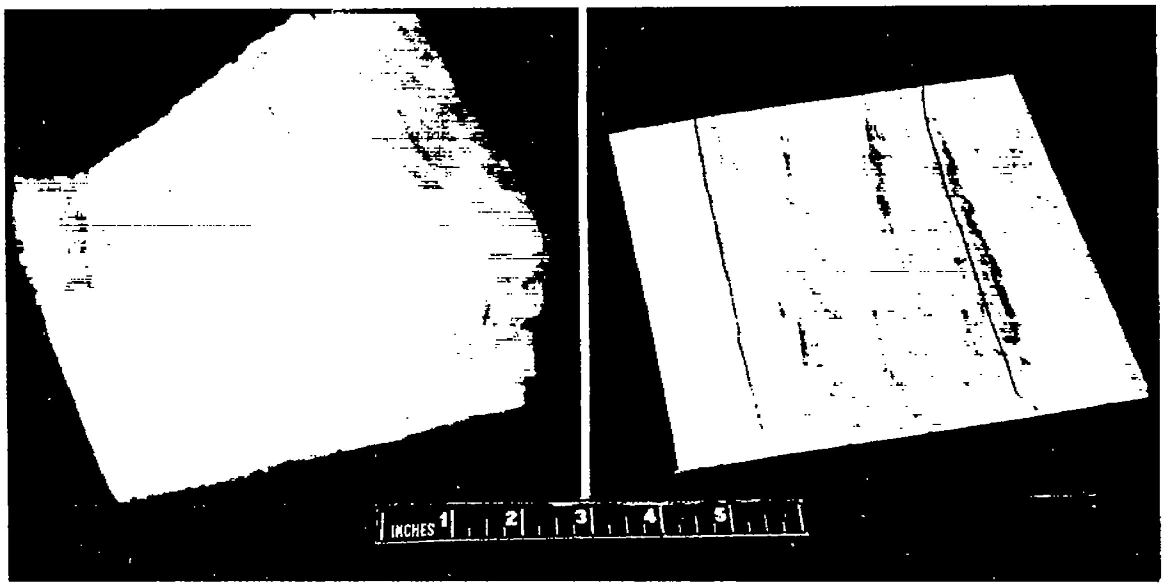


(b) Computed suction-velocity distribution.

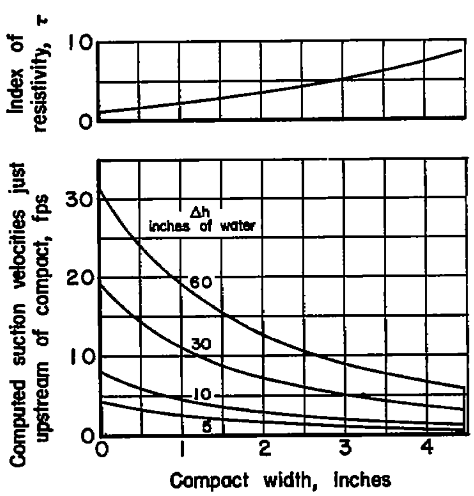


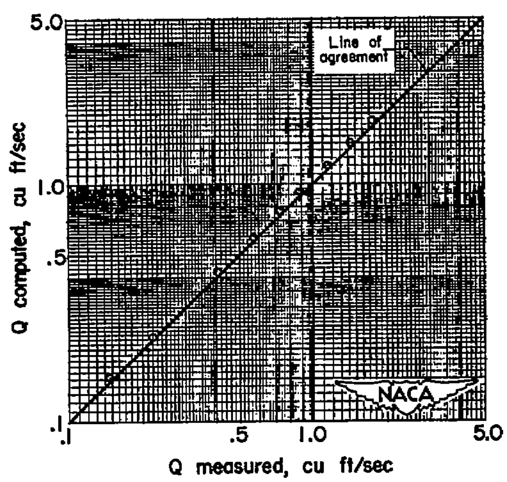
(c) Correlation of computed and measured flow rates for equal values of Δh.

Figure 7.- Fibrous-glass compact with stepped permeability; density from 6 to 24 pounds per cubic foot; thickness = 3/16 inch.



(a) Material arrangement before and after compacting into tapered arrangement of permeability.

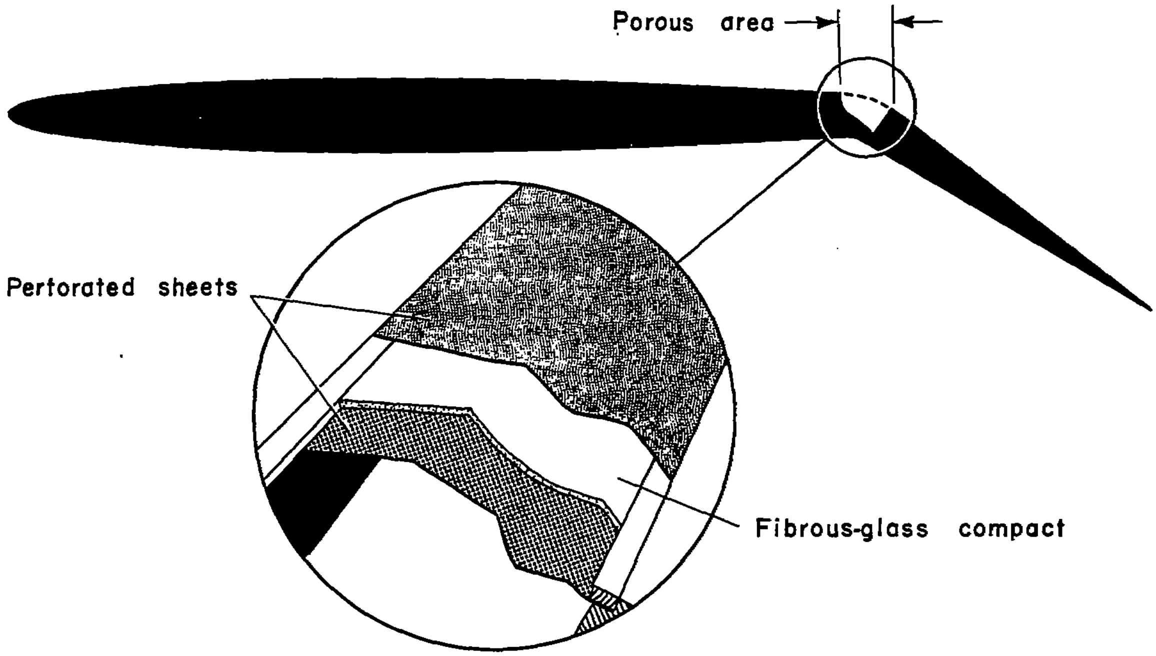




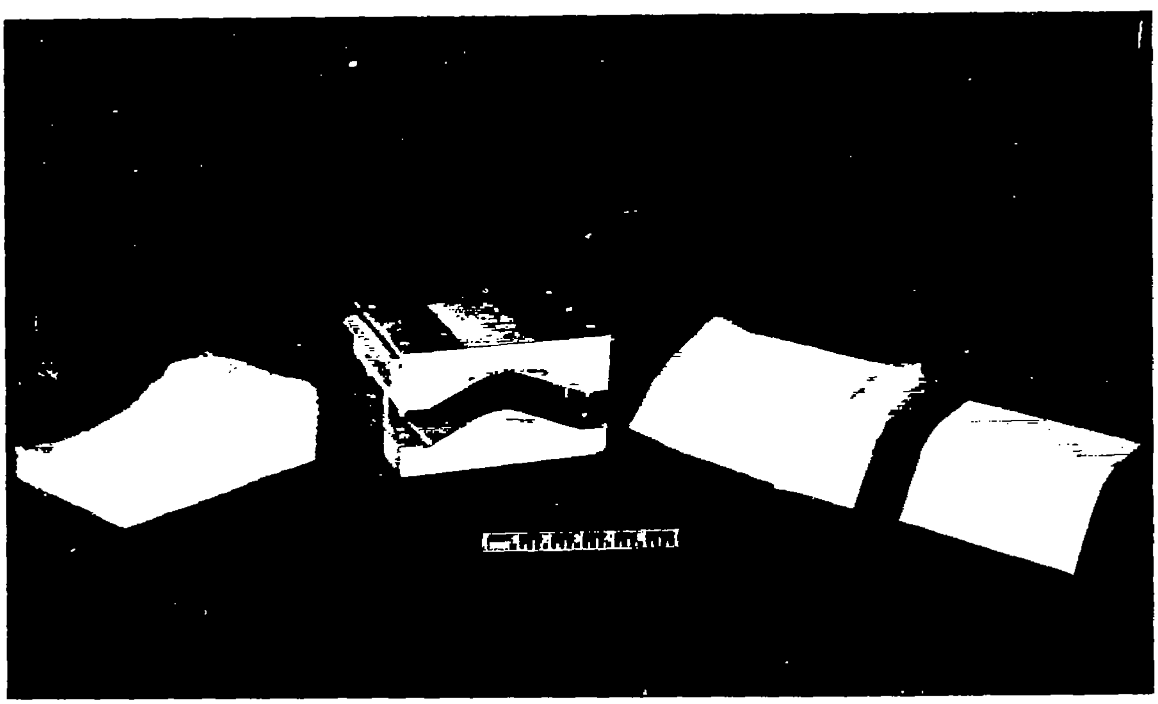
(b) Computed suction-velocity distribution.

(c) Correlation of computed and measured flow rates for equal values of Δh.

Figure 8.- Fibrous-glass compact with tapered permeability; linear density variation from 6 to 24 pounds per cubic foot; thickness = 3/16 inch.



(a) Detail of porous surface.



(b) Molding sequence.

Figure 9.– Typical area suction installation with molded compact.

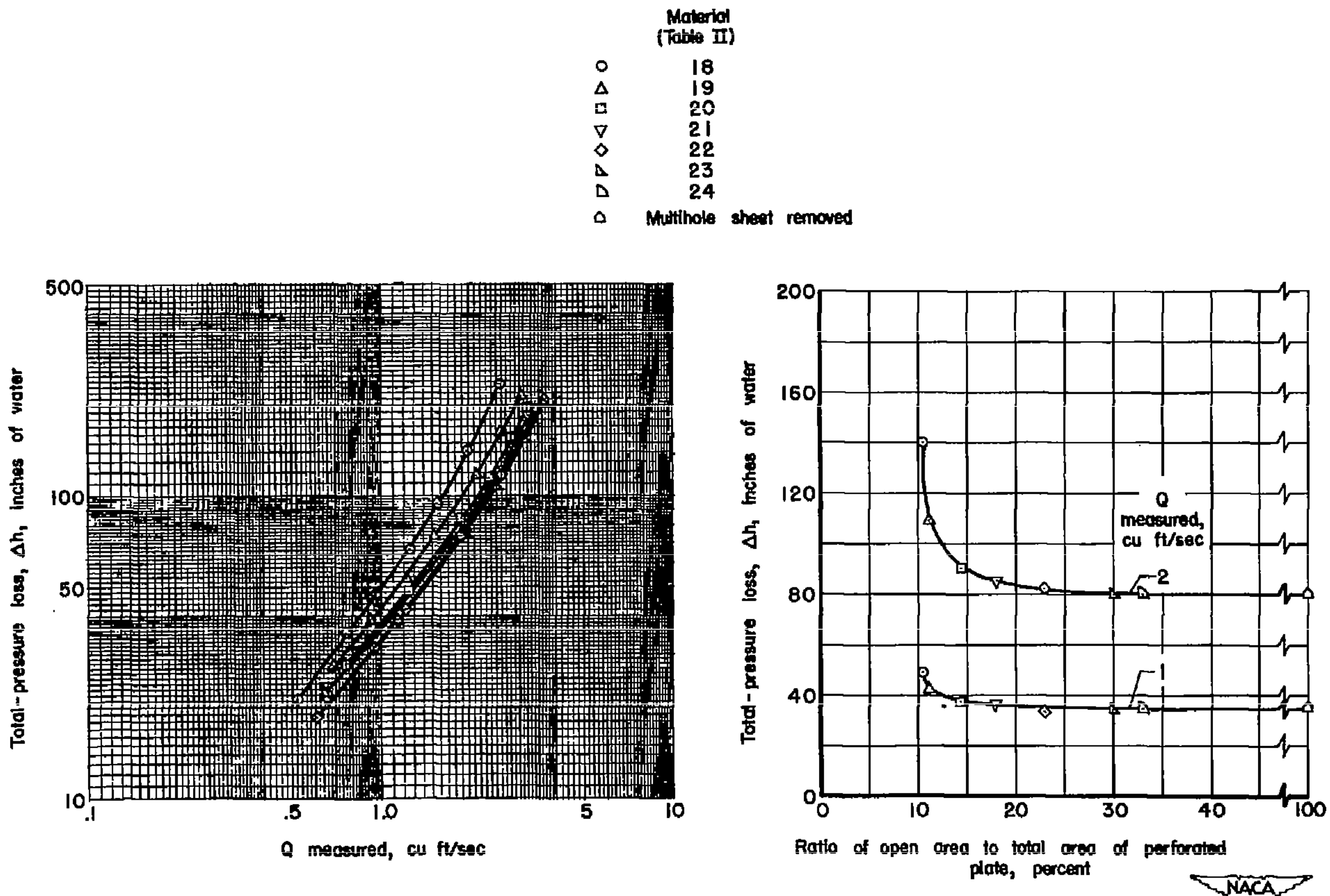


Figure 10.- Effect of open area of a multihole sheet on the flow-resistance characteristics of a fibrous-glass compact; multihole sheet on upstream side of compact; compact thickness = 3/16-inch; compact permeability tapered from a linear density variation from 6 to 24 pounds per cubic foot.

NACA-Langley - 1-26-55 - 1000